

Open: *Space* - Something Corporate
Close: *Counting the Stars* - Waking Ashland

GnatSigh News

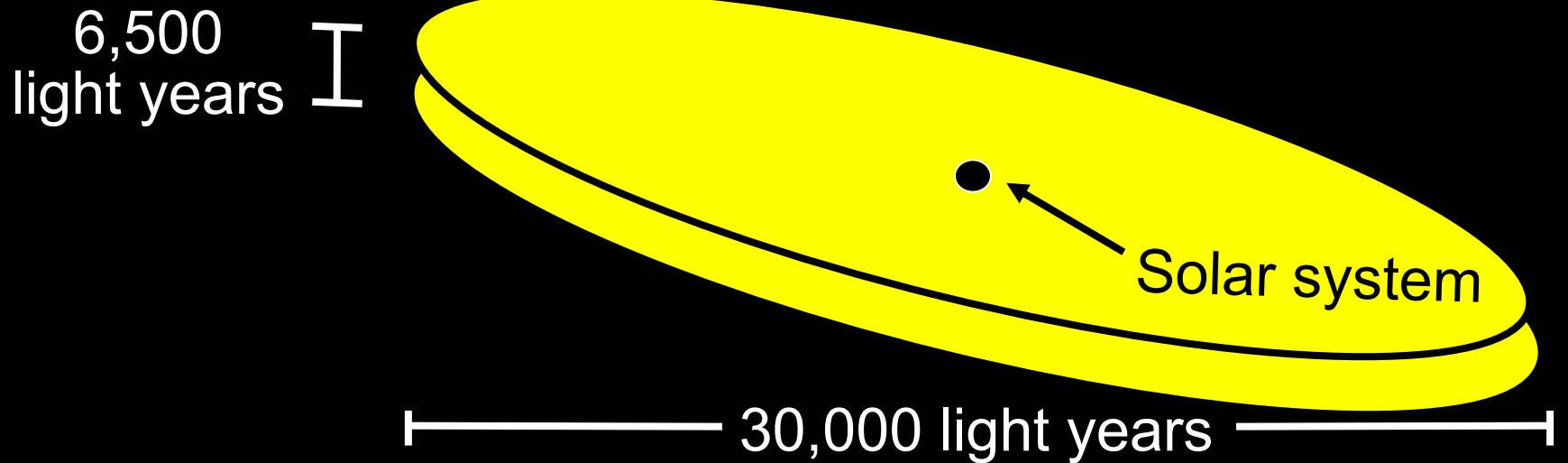
(all the news that fits)

- Website <http://home.fnal.gov/~rocky/NS102/>
- Last class next Tuesday!
- Final Exam
 - 10:30-12:30 Thursday 9 June
 - Help sessions: To be arranged

Lab this week: Big Bang Nucleosynthesis

A view of the universe, circa 1905

1) Arrangement:



2) Composition: Starz' in the 'hood

3) Static (unchanging in time)

4) Origin???

5) Space and time are absolute

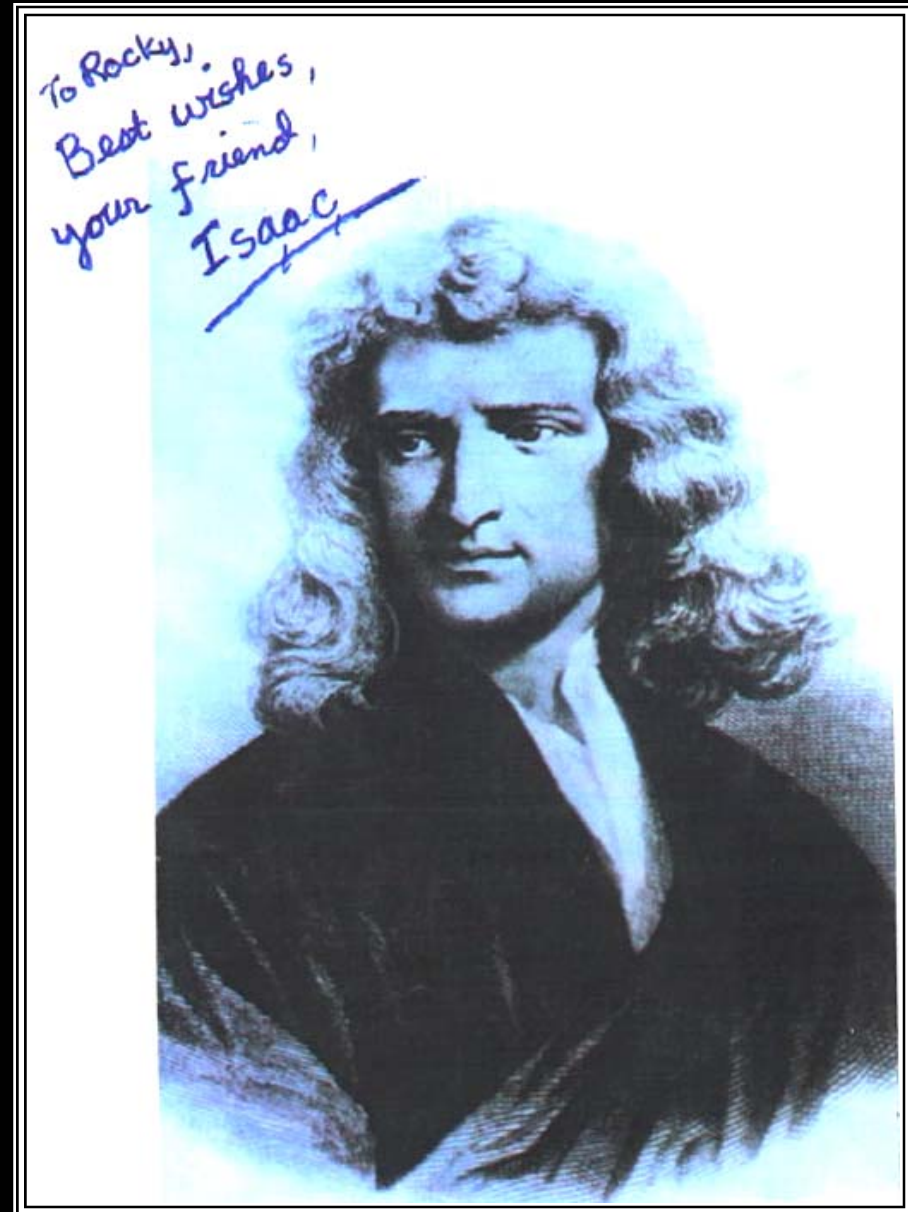
Space and Time Before Einstein

***Absolute space,
in its own nature,
without relation
to anything external,
remains always similar
and immovable.***

Isaac Newton

1687

***Philosophiae Naturalis
Principia Mathematica***





"When the Special Theory of Relativity began to germinate in me, I was visited by all sorts of nervous conflicts... I used to go away for weeks in a state of confusion."

"A storm broke loose in my mind."

Einstein, ca. 1905

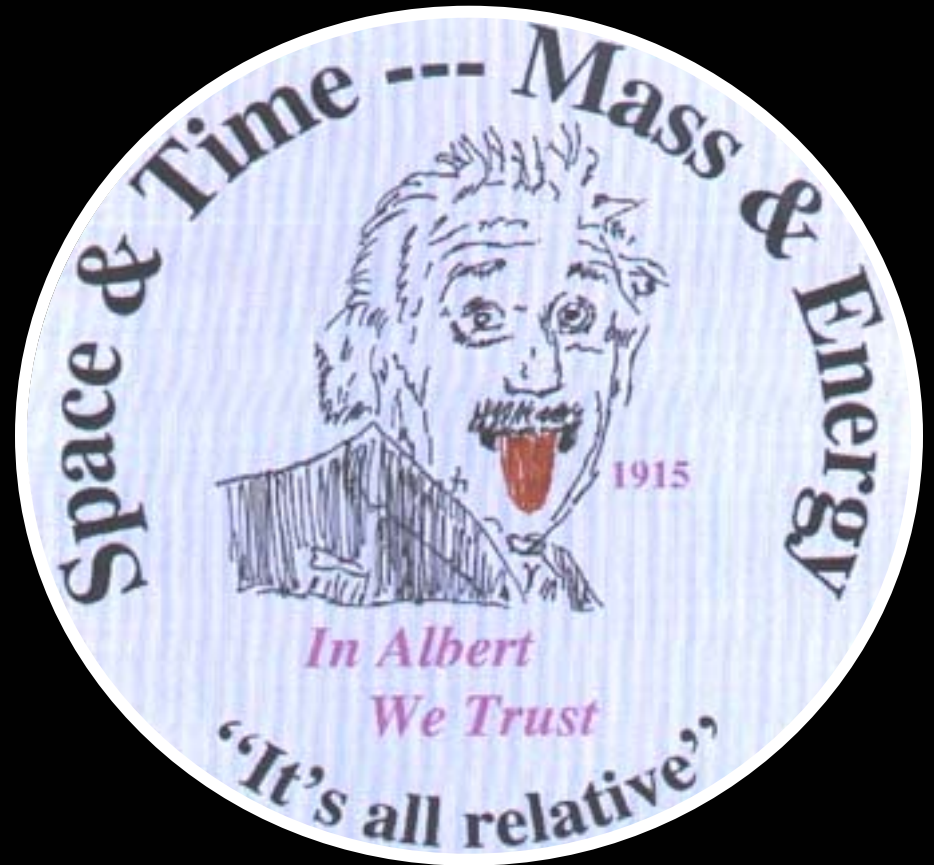
Space and Time After Einstein

Space and time
are related.

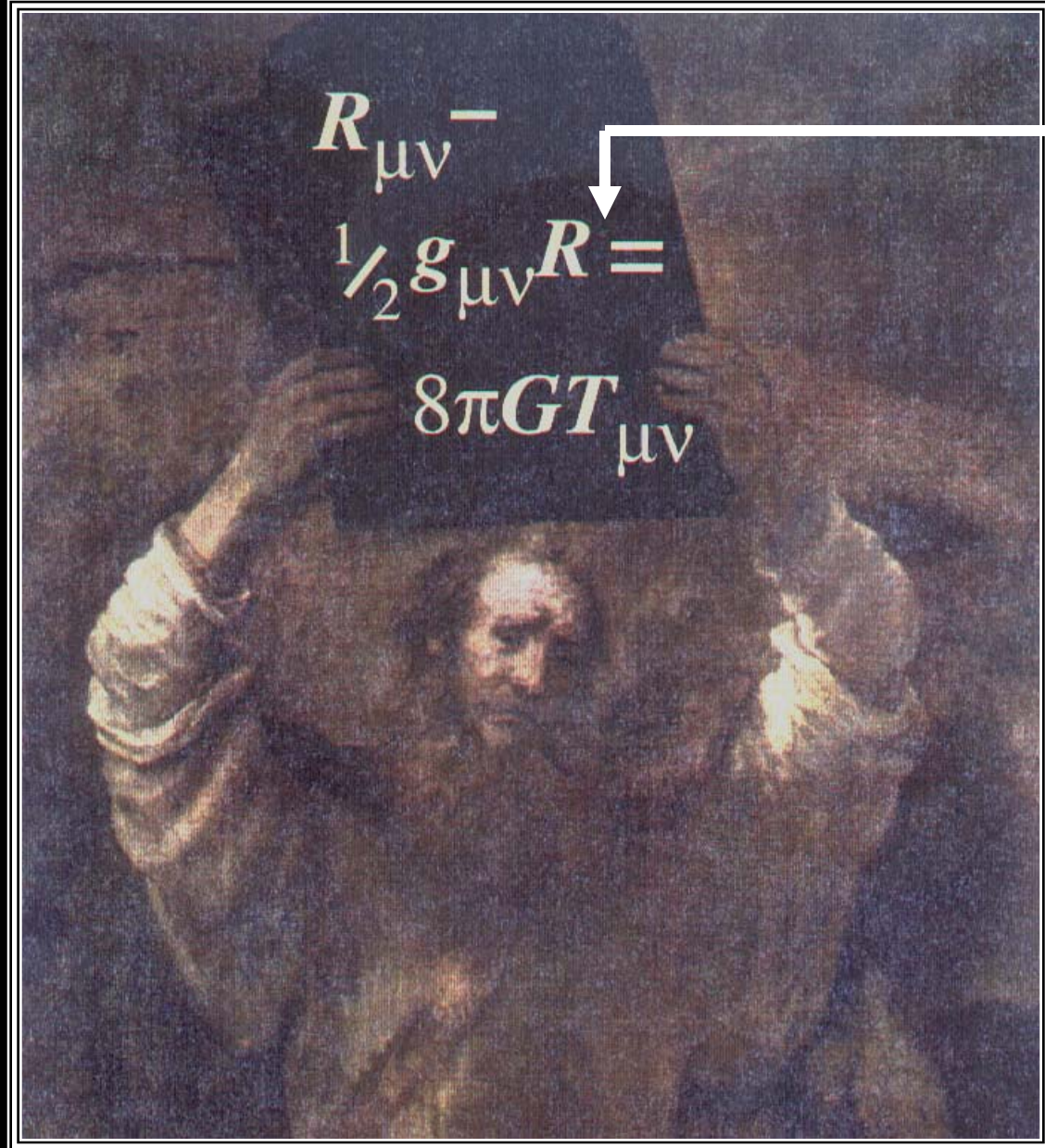
Albert Einstein
1905

Space is dynamic
(curved, warped, bent).

Albert Einstein
1915



Modern Laws of Genesis



$$R_{\mu\nu}$$

$$\frac{1}{2}g_{\mu\nu}R =$$

$$8\pi GT_{\mu\nu}$$

$$+\Lambda g_{\mu\nu}$$

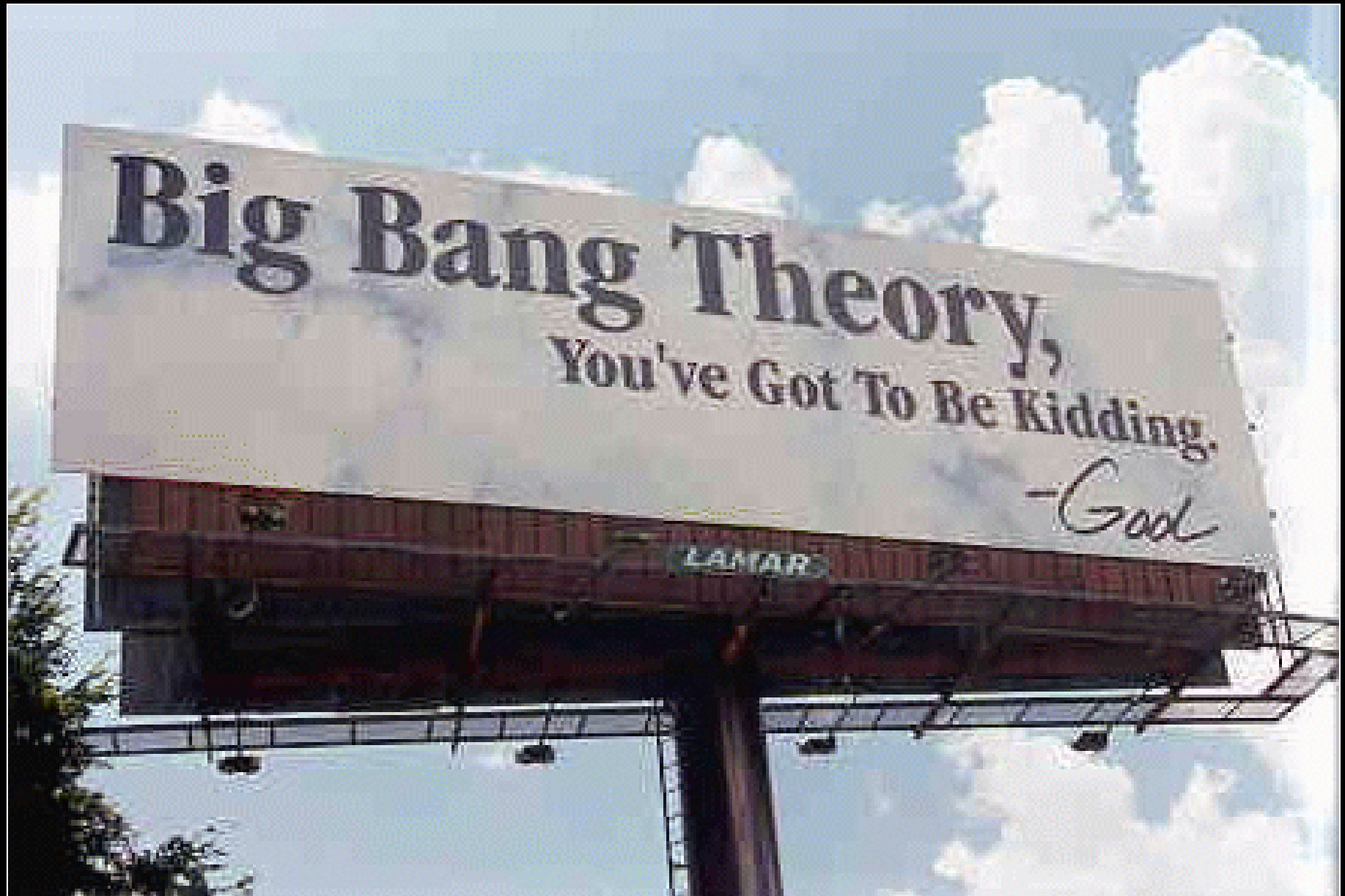
Einstein's Cosmic Legacy

The origin & destiny
of the universe are
amenable to human
inquiry!

Cosmology is a science!



The Big Bang



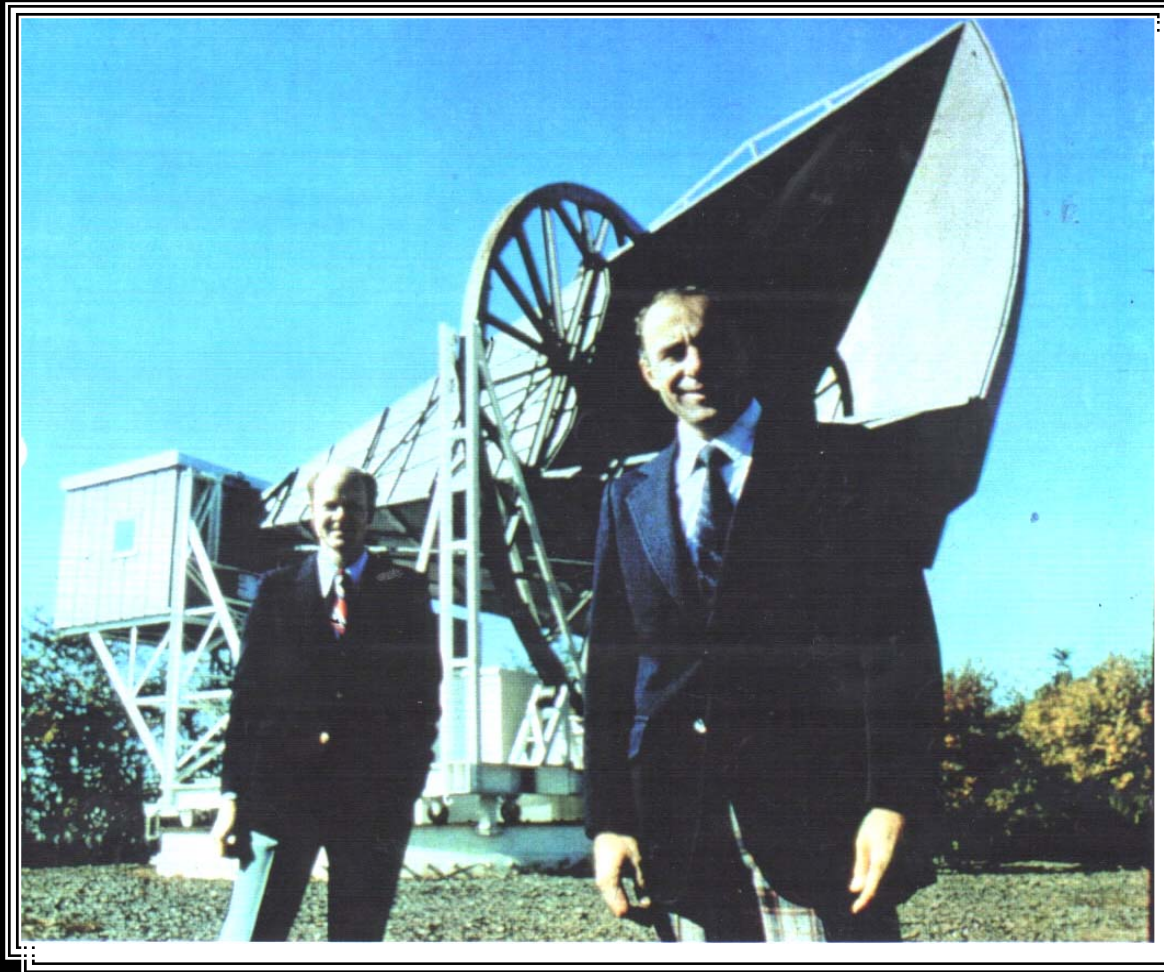
Space expands.

**Edwin Hubble
1929**

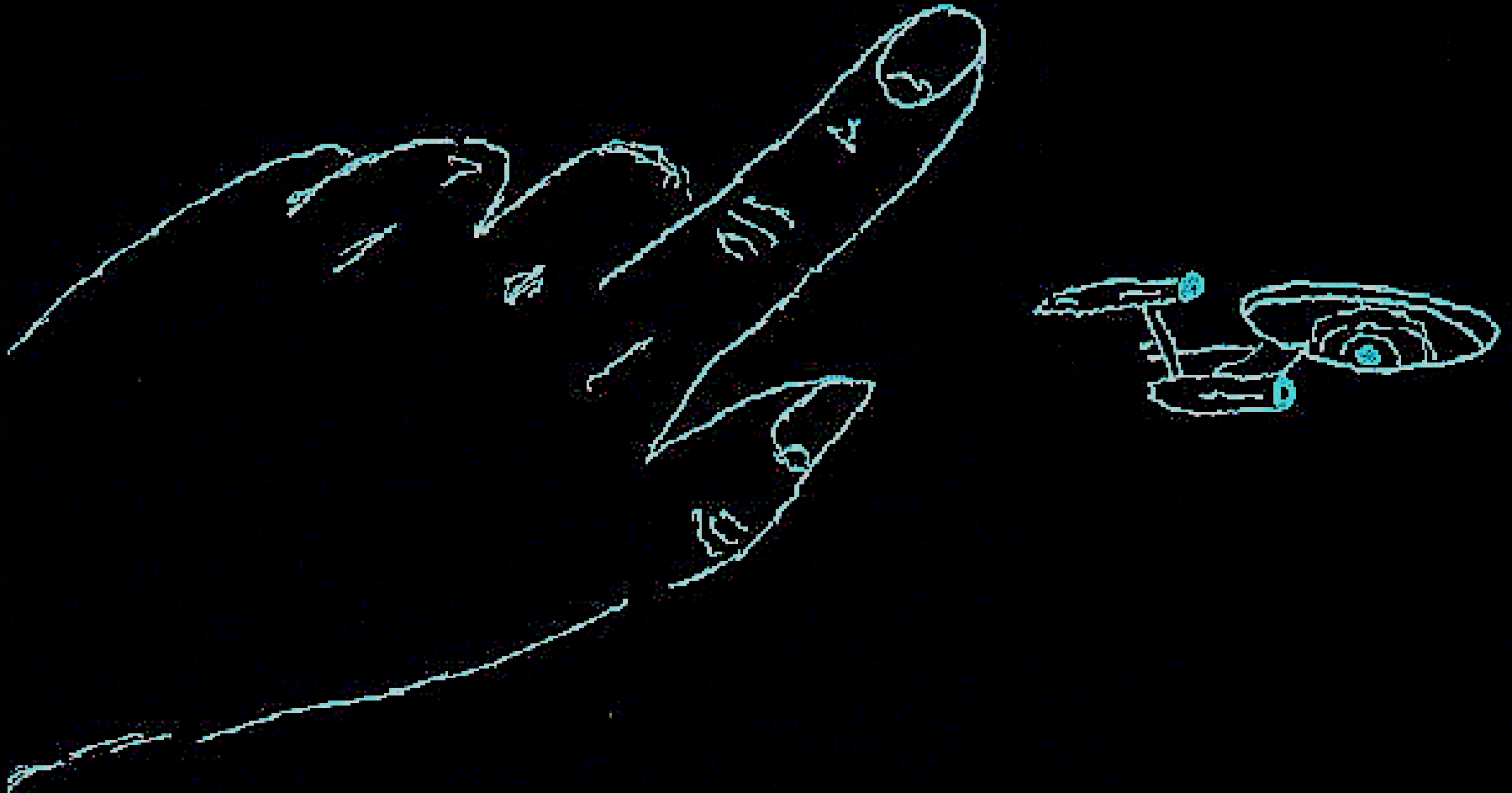


**The universe
is radiant.**

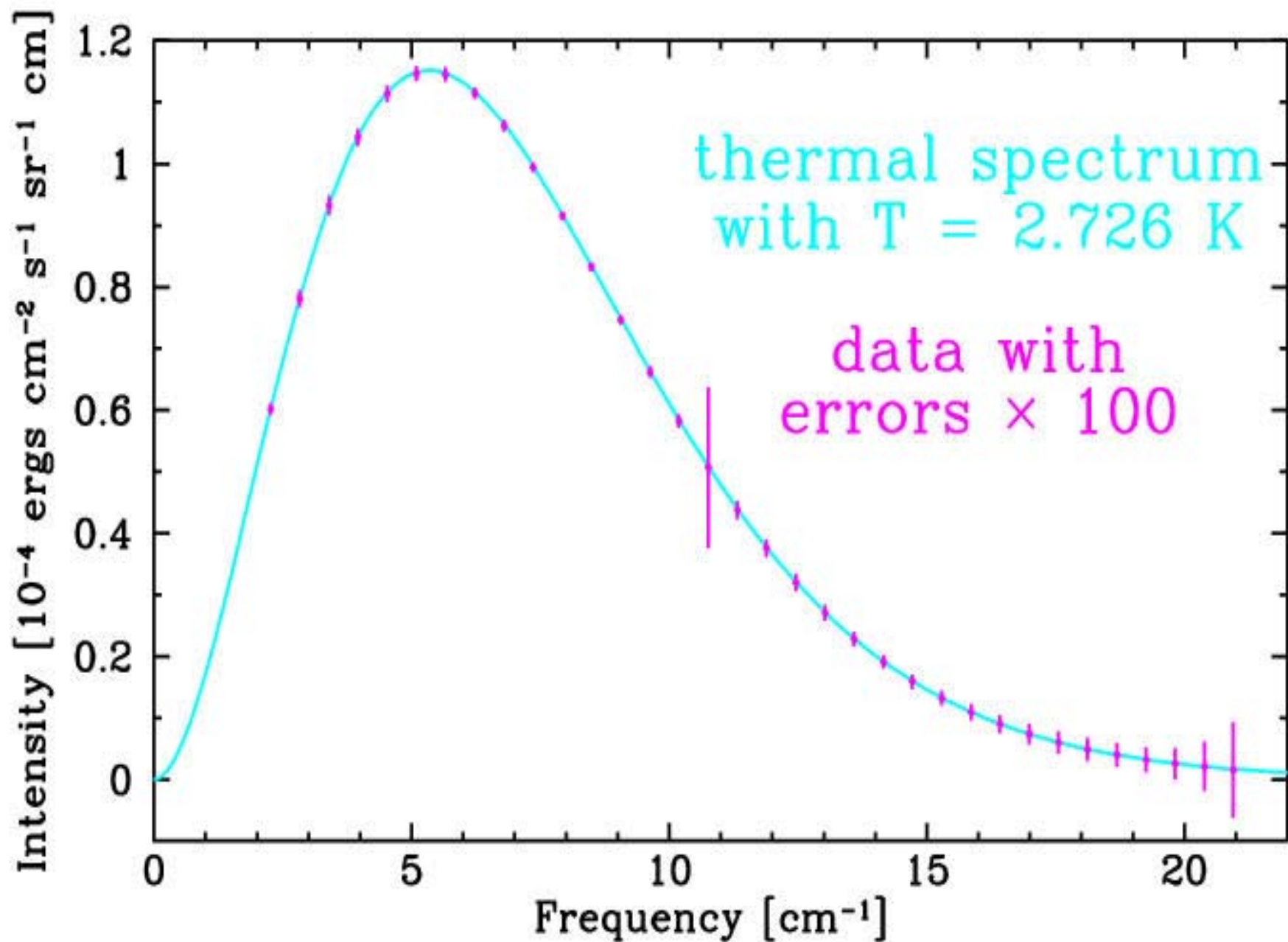
**Arno Penzias
Robert Wilson
1965**



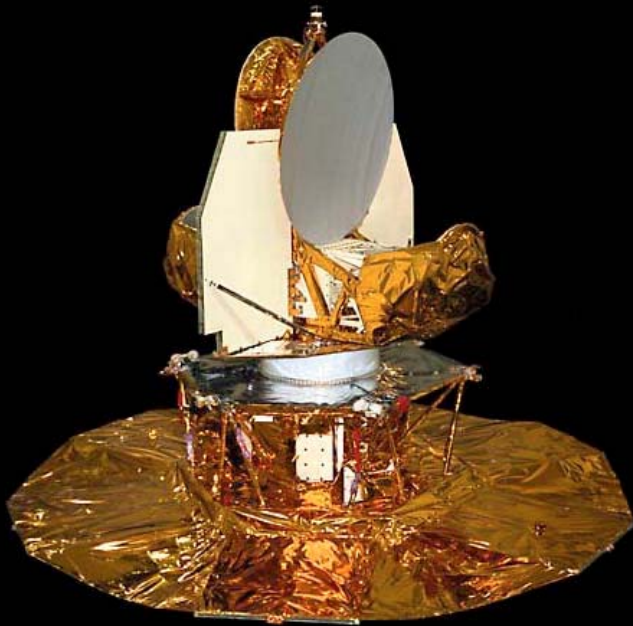
Cosmic background radiation



$$T = 3K = -454^{\circ} F$$



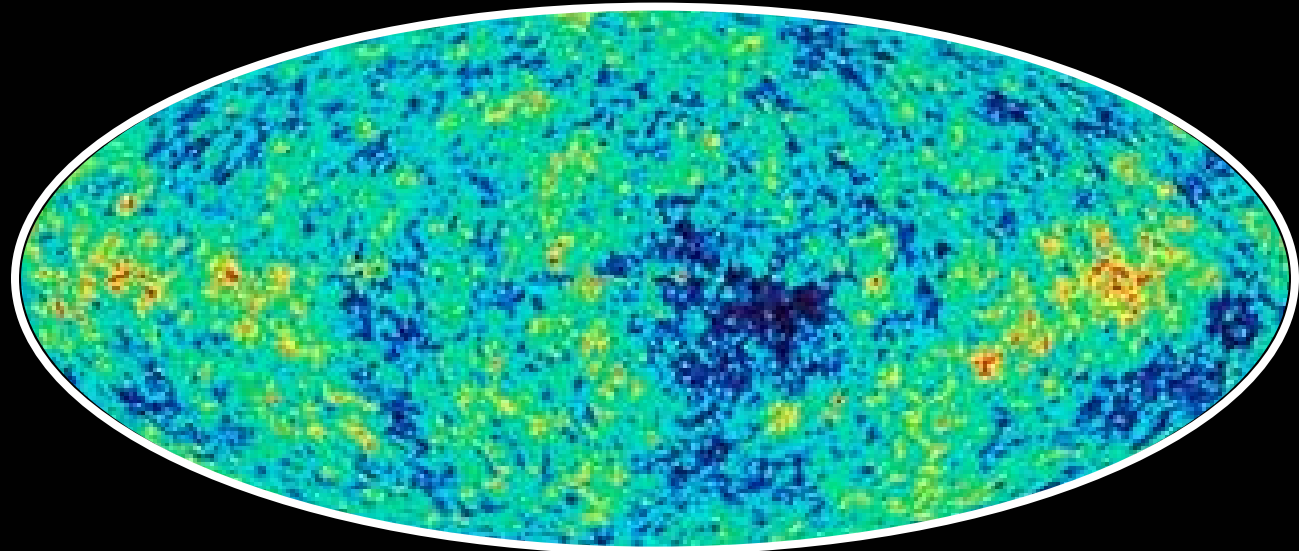
Cosmic Radiation 2005



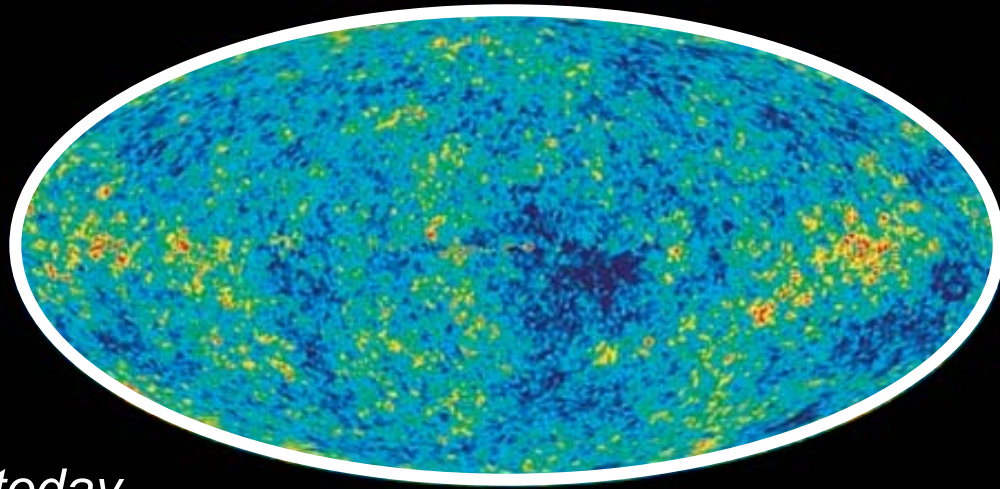
MAP990369

WMAP

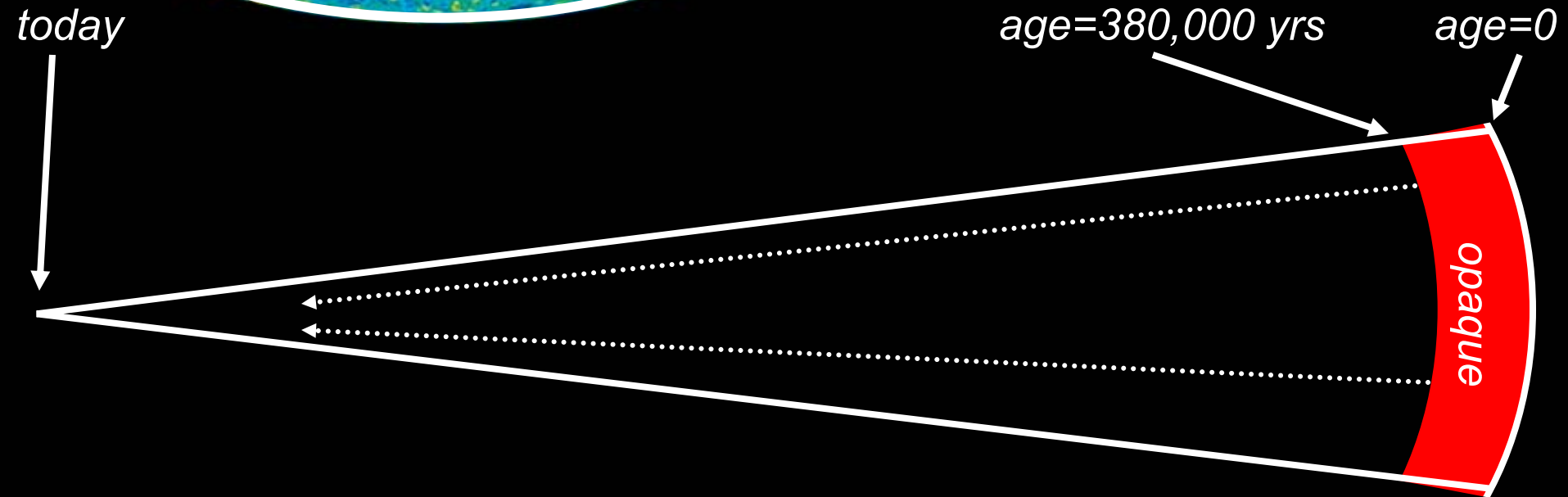
2.99997° 3° 3.00003°



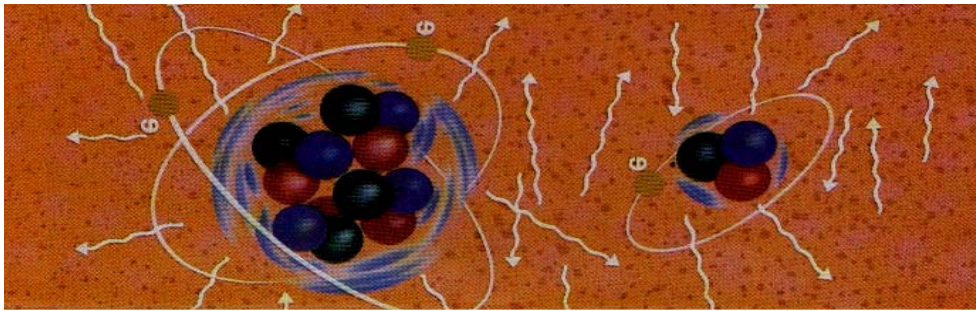
Looking out in space is looking back in time.



**CBR: a snapshot of the
universe 380,000 AB**

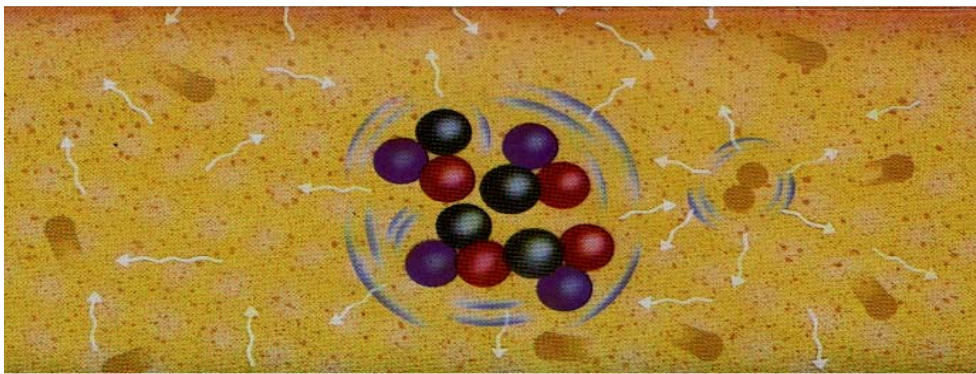


**380,000
years**



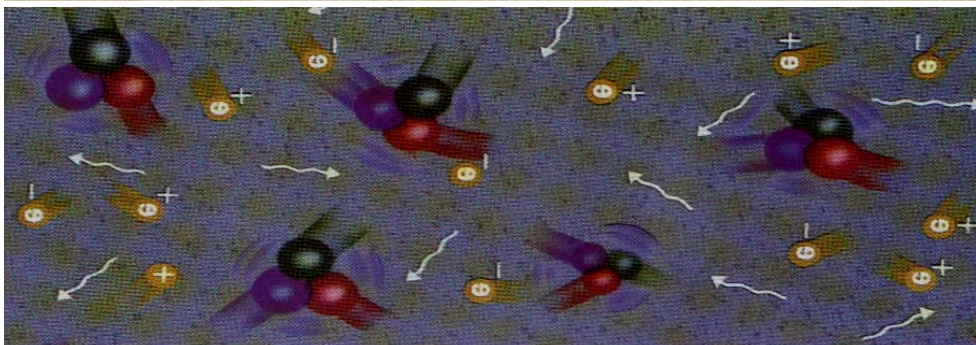
**atoms
form**

**3
minutes**



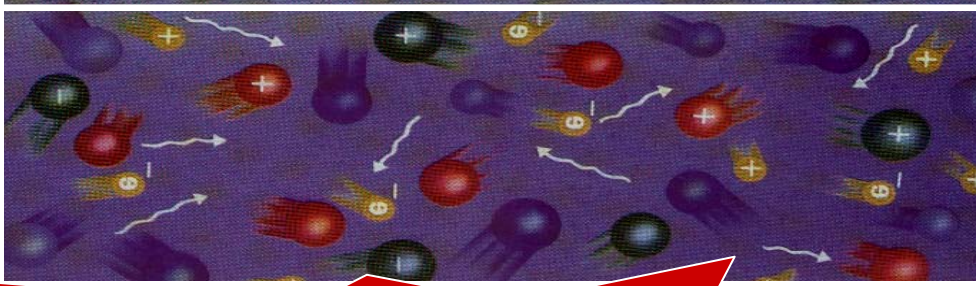
**nuclei
form**

**1-micro
second**



**neutrons
protons
form**

**4-pico
seconds**



**primordial
soup**

BANG!

Periodic table - chemist

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra		Rf	Db	Sg	Bh	Hs	Mt	Uun	Uuu	Uub						
			La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
			Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

Periodic table - cosmologist

H

He

Metals

The Universe today:

73%	Hydrogen	(10^{-5} ^2H -deuterium)
26%	Helium	(10^{-5} ^3He)
1%	Metals	

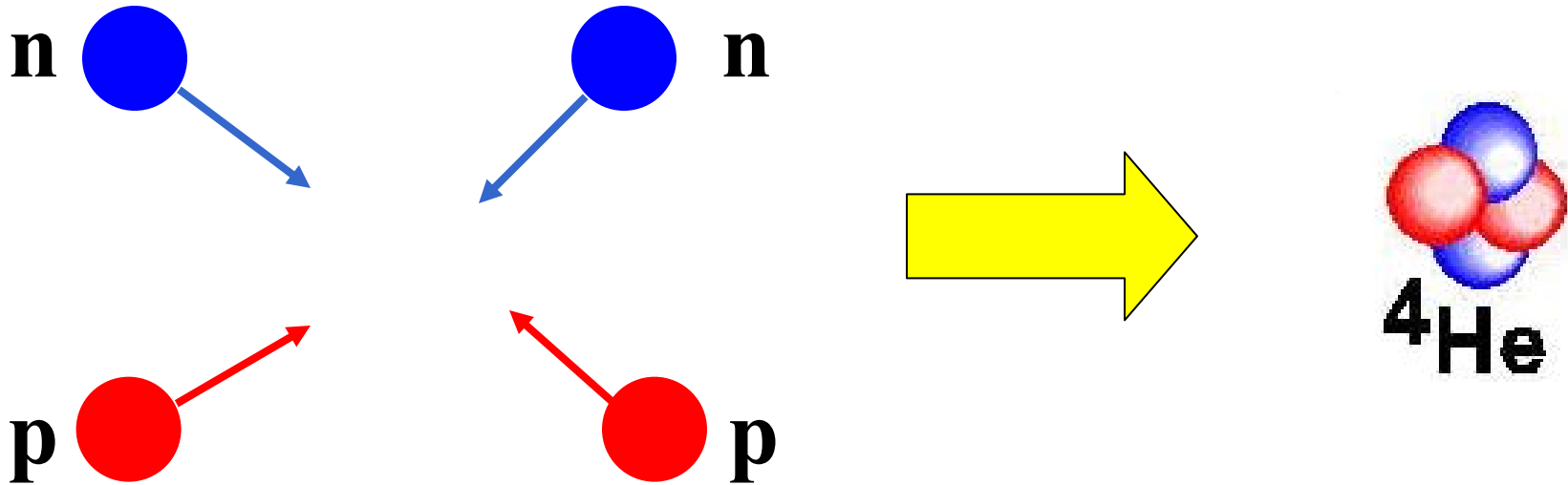
The Universe 3 minutes AB:

76%	Hydrogen	(10^{-5} ^2H -deuterium)
24%	Helium	(10^{-5} ^3He)
$10^{-8}\%$	Lithium	

Nucleosynthesis

...the process of assembling nuclei either by nuclear fusion or nuclear fission.

Nuclear Alchemy



nucleus	mass (AMU)	sum (AMU)
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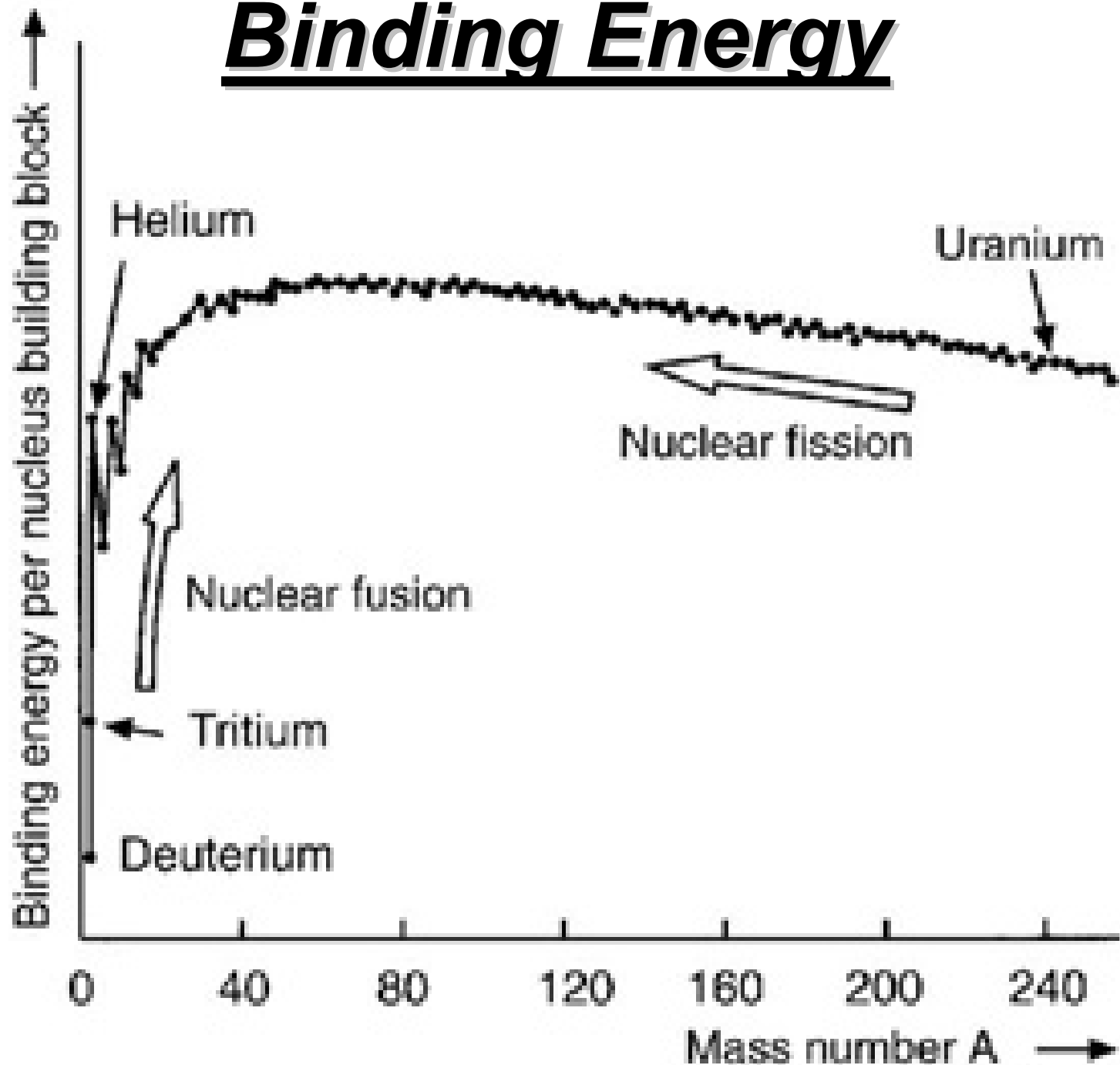
p	1.0073	4.0320
p	1.0073	
n	1.0087	
n	1.0087	

${}^4\text{He}$	4.0026
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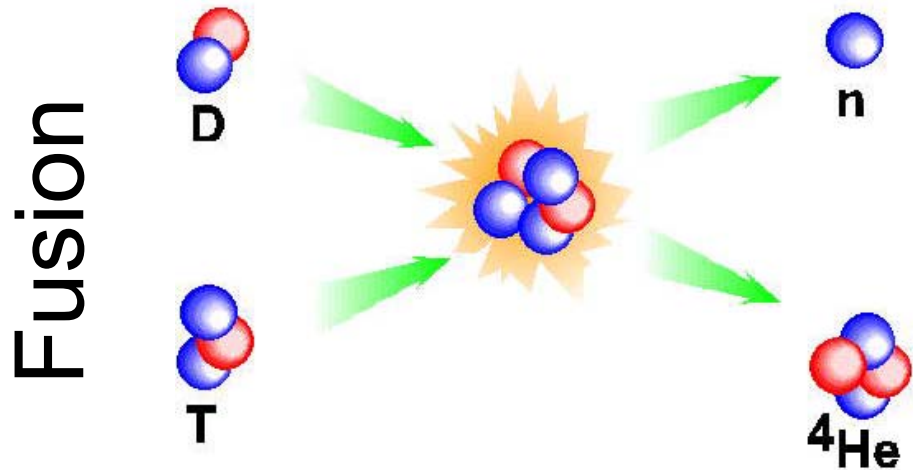
$$m_{{}^4\text{He}} < 2m_p + 2m_n$$

Difference in mass (Binding Energy) released as energy
à la $E = Mc^2$

Binding Energy



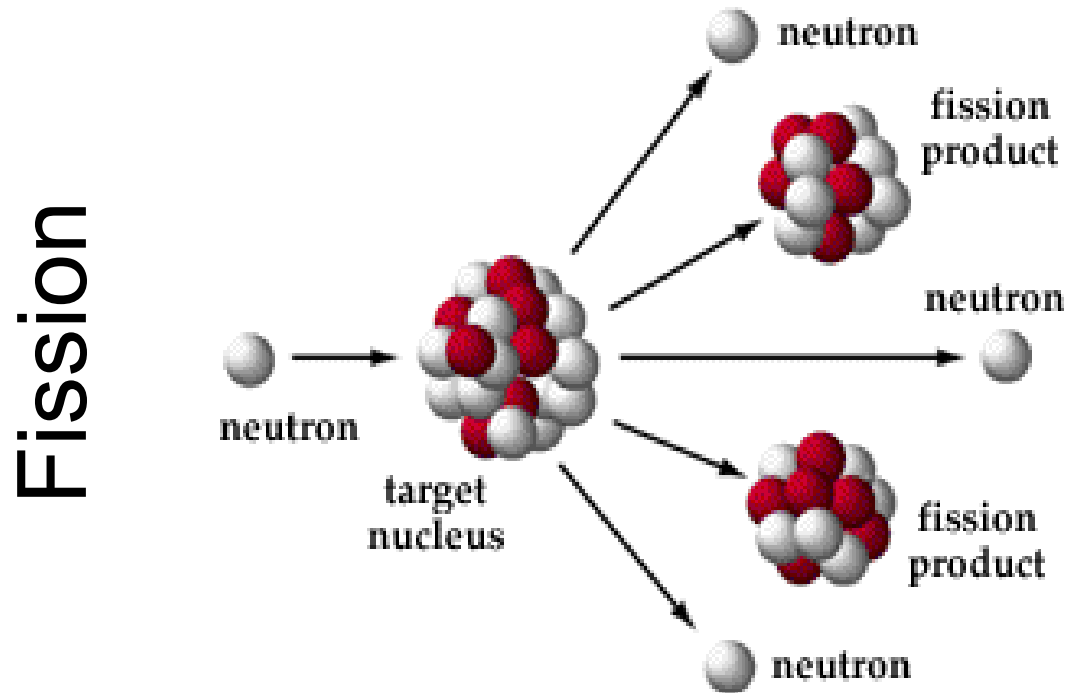
Binding Energy



nucleus	mass (AMU)	sum (AMU)	difference (AMU)
D	2.0141	5.0301	0.0188
T	3.0160		
n	1.0087	5.0113	
⁴ He	4.0026		

Difference in mass released as energy à la $E = Mc^2$

Nuclear Alchemy



$$m_n + m_{\text{TARGET}} > m_{\text{PRODUCTS}}$$

Difference in mass released as energy à la $E = Mc^2$

Nucleosynthesis

...the process of assembling nuclei either by nuclear fusion or nuclear fission.

Big Bang nucleosynthesis (BBN): within the first three minutes of the universe and is responsible for most of the deuterium, helium-4, helium-3, and lithium-7. No elements heavier than lithium could be formed.

Stellar nucleosynthesis: creates most of the heavier elements between lithium and iron.

Supernova nucleosynthesis: produces most of the elements heavier than iron.

Cosmic ray spallation: produces some light elements like lithium and boron.

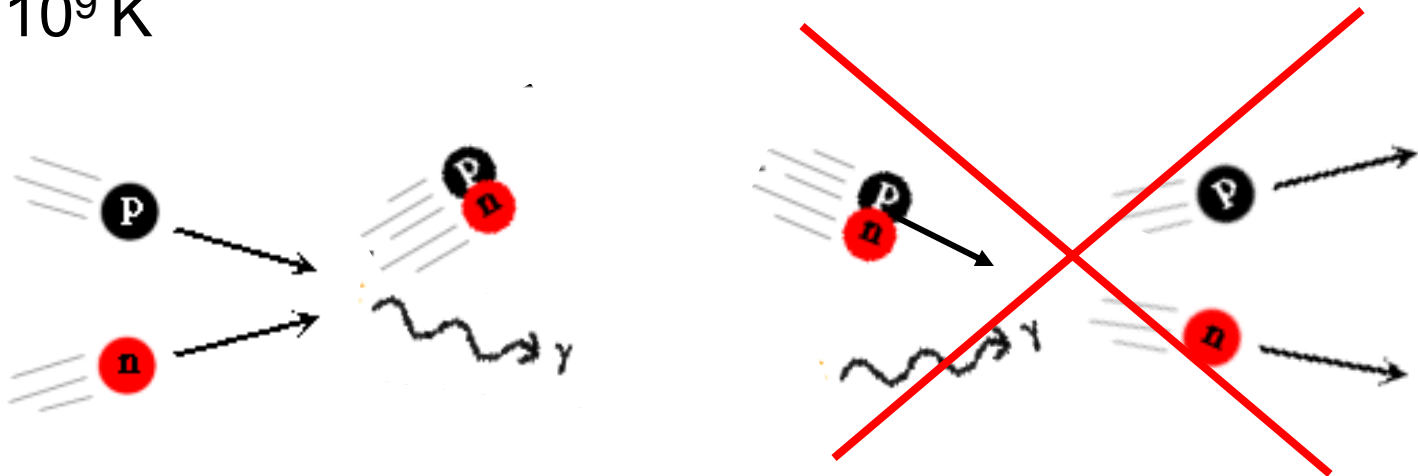
Big Bang Nucleosynthesis

1. $T \gg 10^{10} \text{ K}$



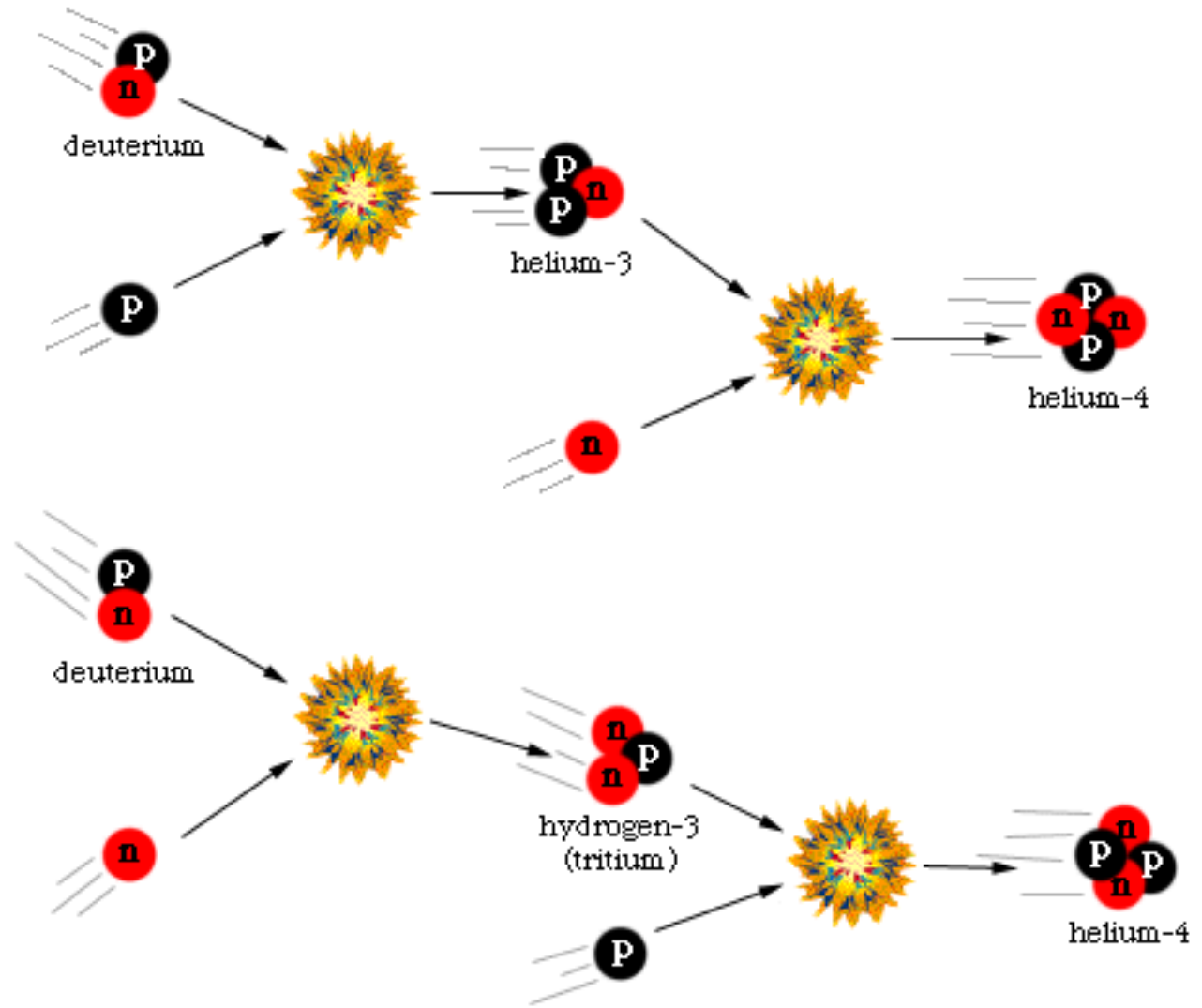
(Deuterium has a low binding energy)

2. $T \approx 10^9 \text{ K}$



Big Bang Nucleosynthesis

3. $T \lesssim 10^9 \text{ K}$

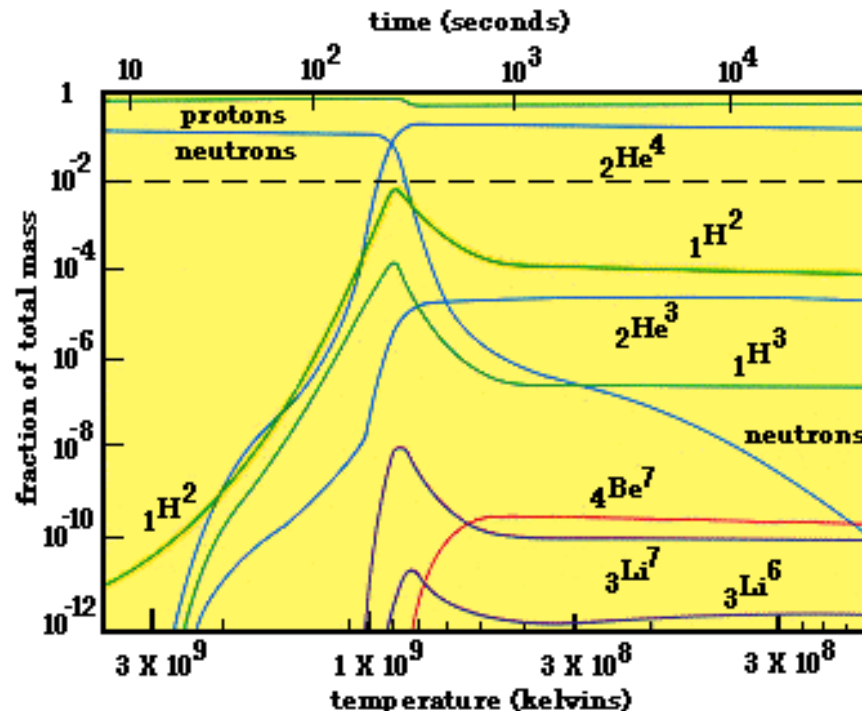


(Helium-4 has a high binding energy)

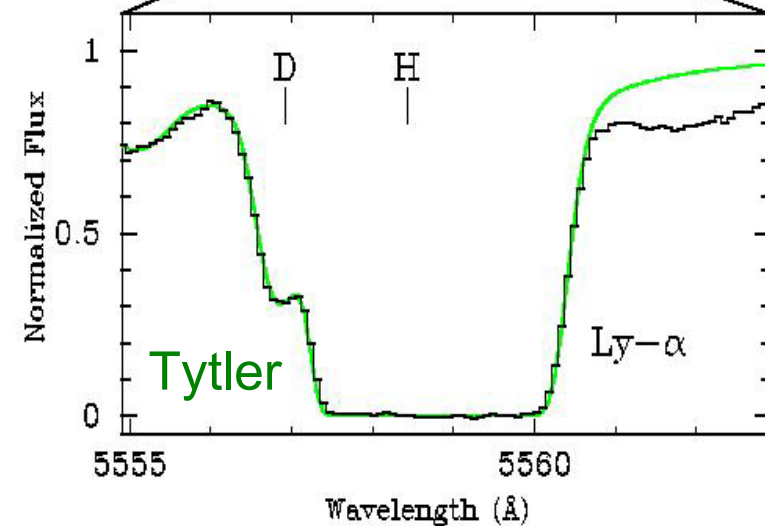
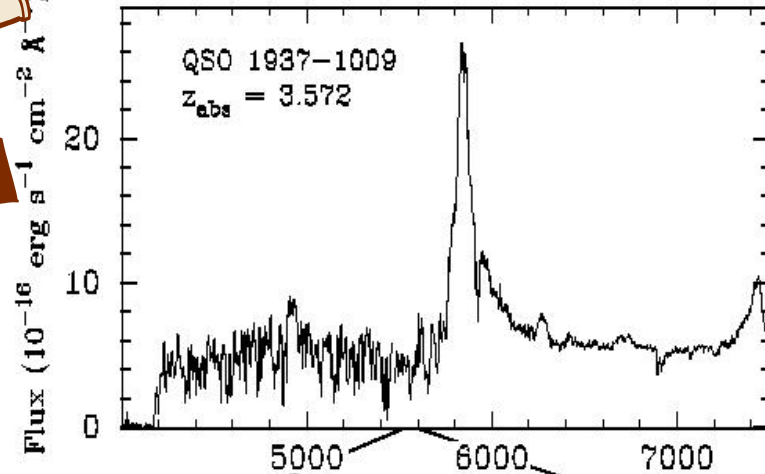
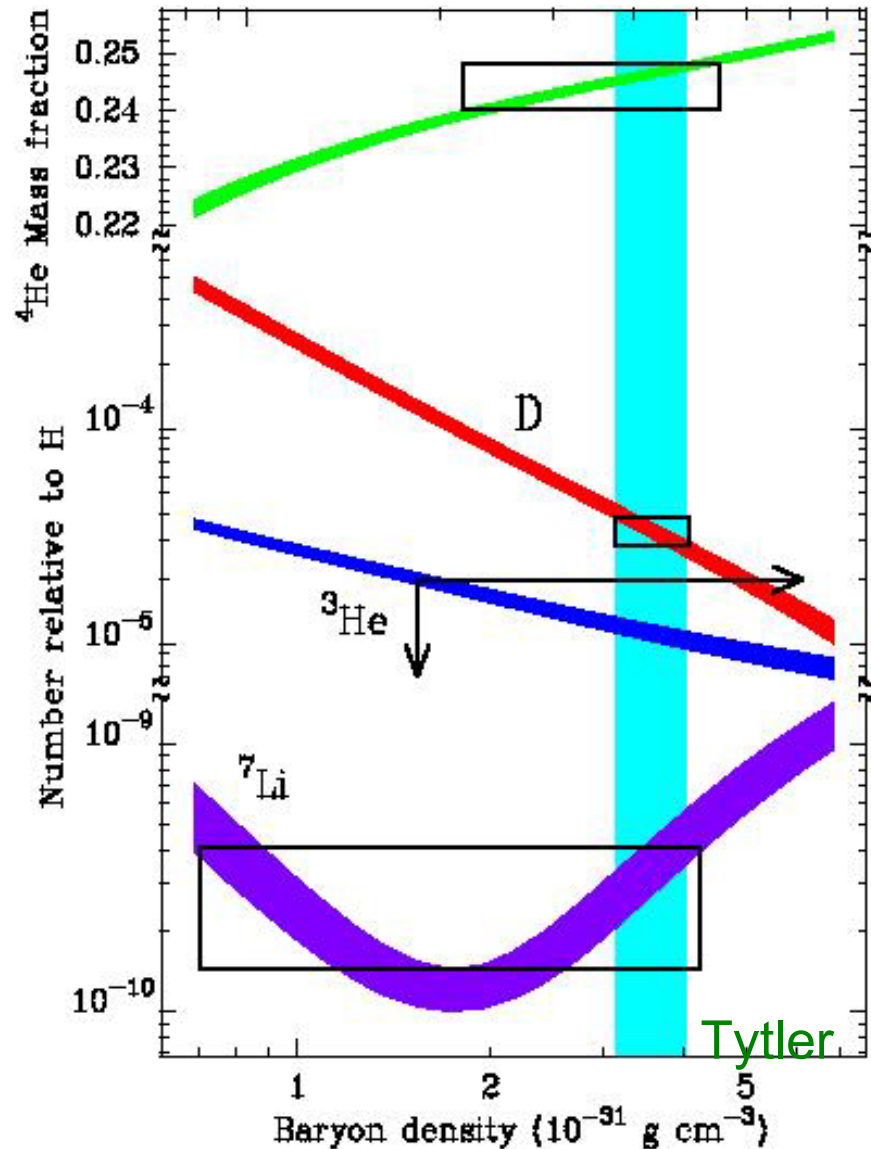
Big Bang Nucleosynthesis

4. $T \lll 10^9 \text{ K}$

- neutrons decay or absorbed into helium
- universe consists mostly of protons and helium
- $p + \text{helium} \rightarrow$ (no stable element with $A=5$)
- $\text{helium} + \text{helium} \rightarrow$ (no stable element with $A=8$)
- temperature too low for nucleosynthesis

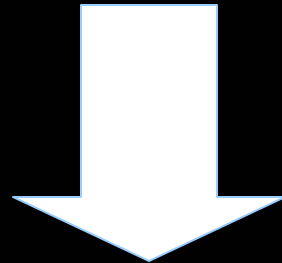


Big Bang Nucleosynthesis



The Universe 3 minutes AB:

Big bang (rate of change of the temperature)
Nuclear physics (binding energies, reactions)

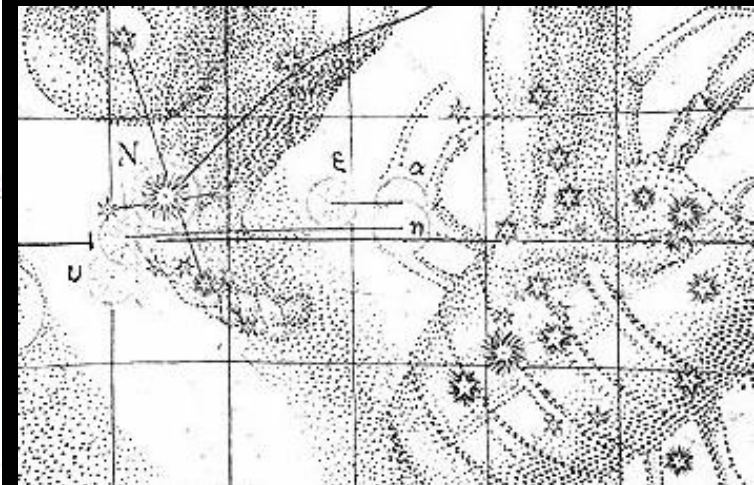
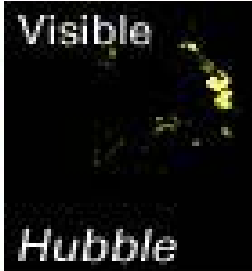


76%	Hydrogen	(10^{-5} ^2H -deuterium)
24%	Helium	(10^{-5} ^3He)
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Kepler's supernova

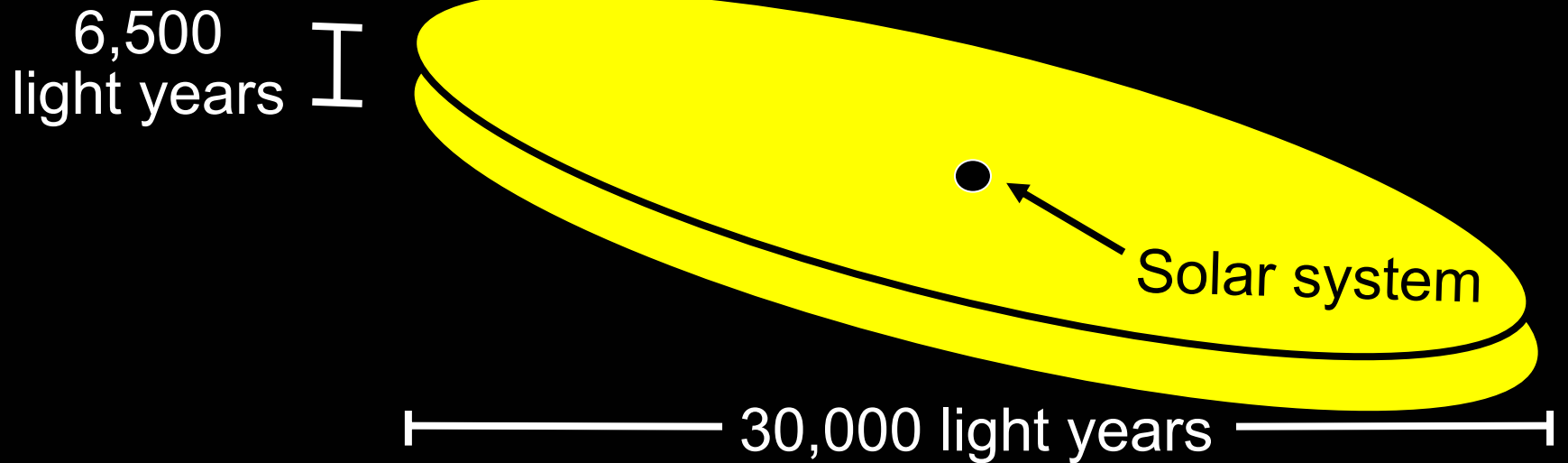


Observed 1604
in Ophiuchus
Peak magnitude = -2.25
Distance < 10 kpc



A view of the universe, circa 1905

1) Arrangement:



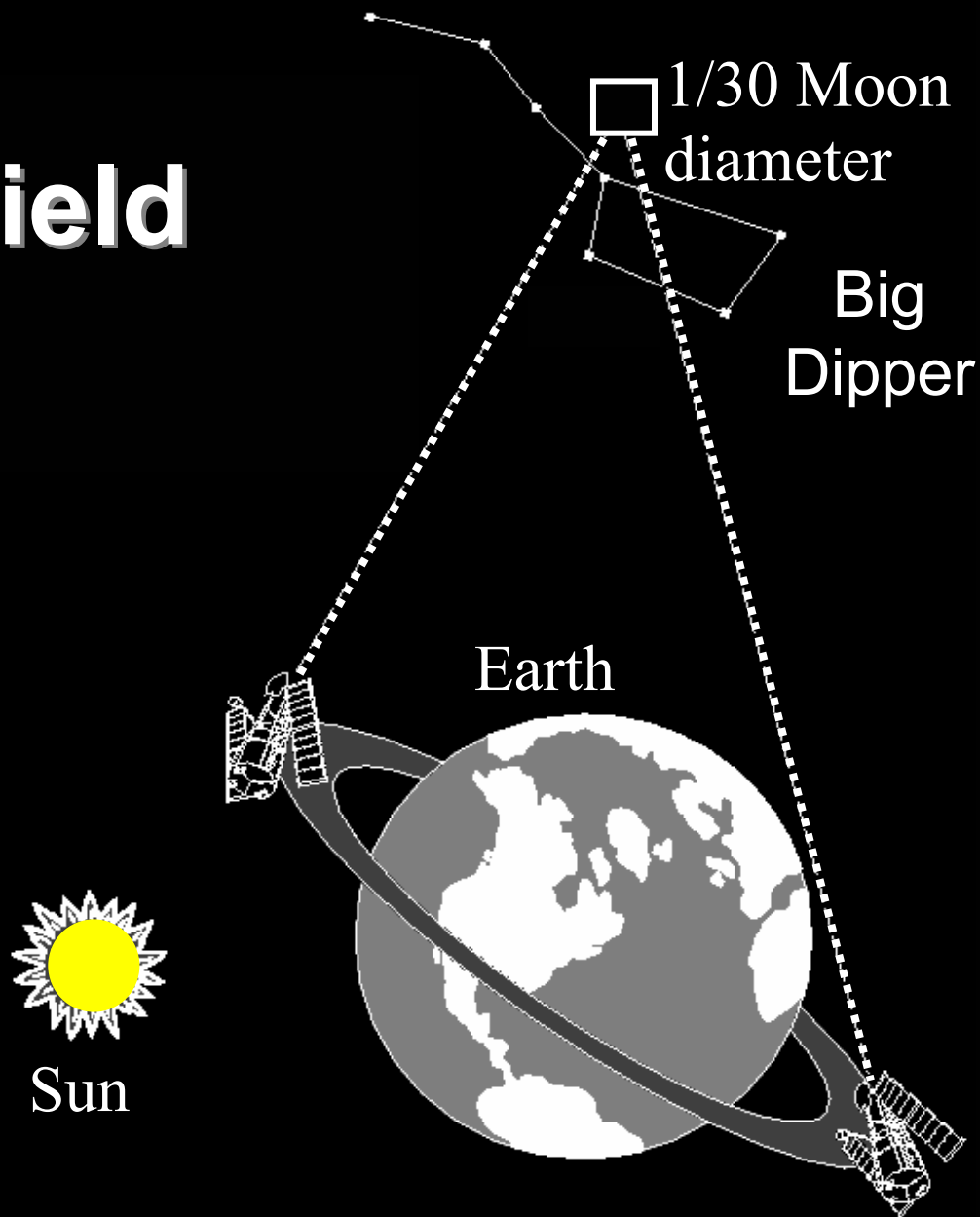
2) Composition: Starz' in the 'hood

3) Static (unchanging in time)

4) Origin???

5) Space and time are absolute

Hubble Deep Field

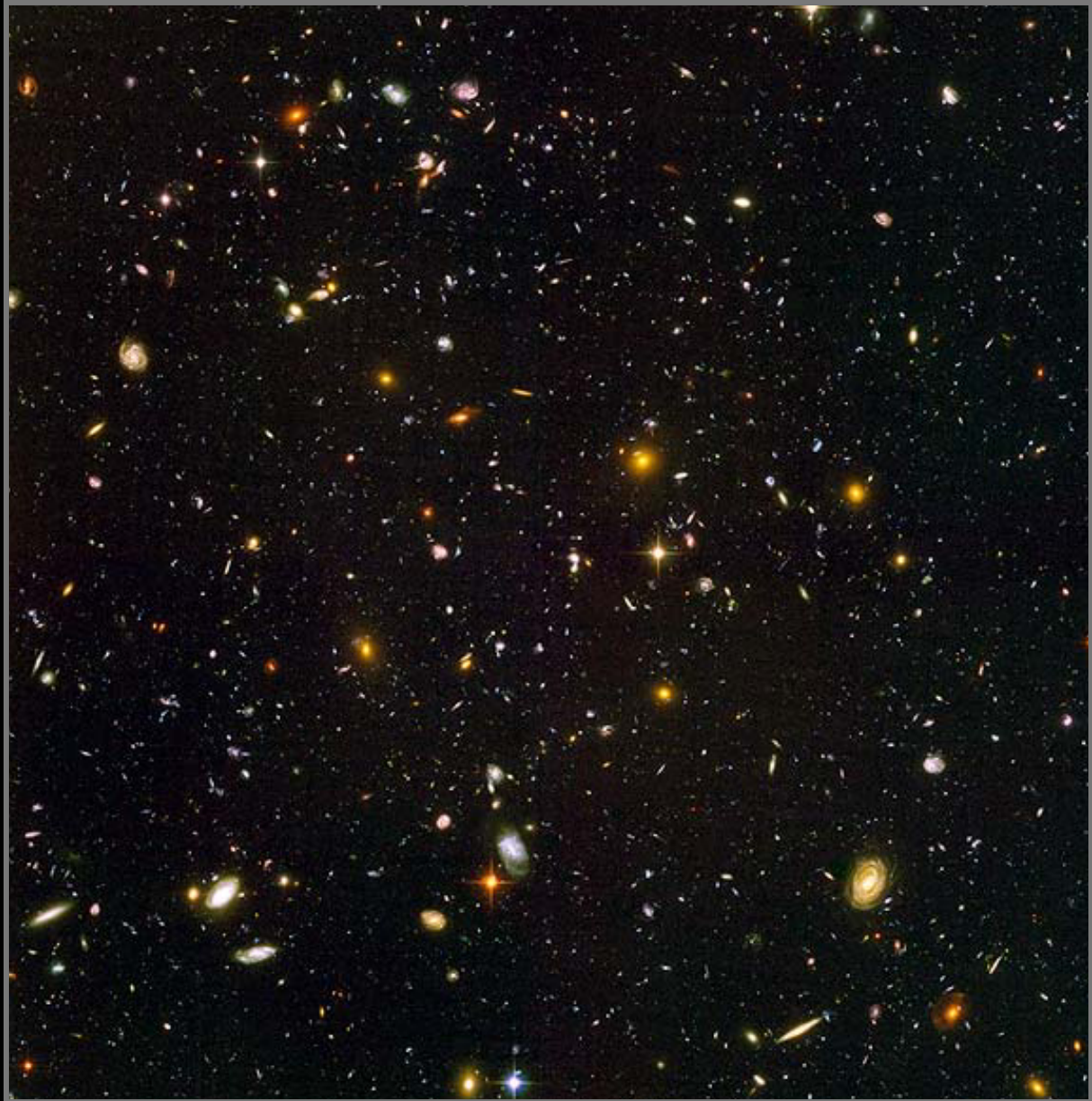


The Hubble Ultra Deep Field

UNIVERSE
OF
GALAXIES

3000
here →

50 billion
over entire
sky



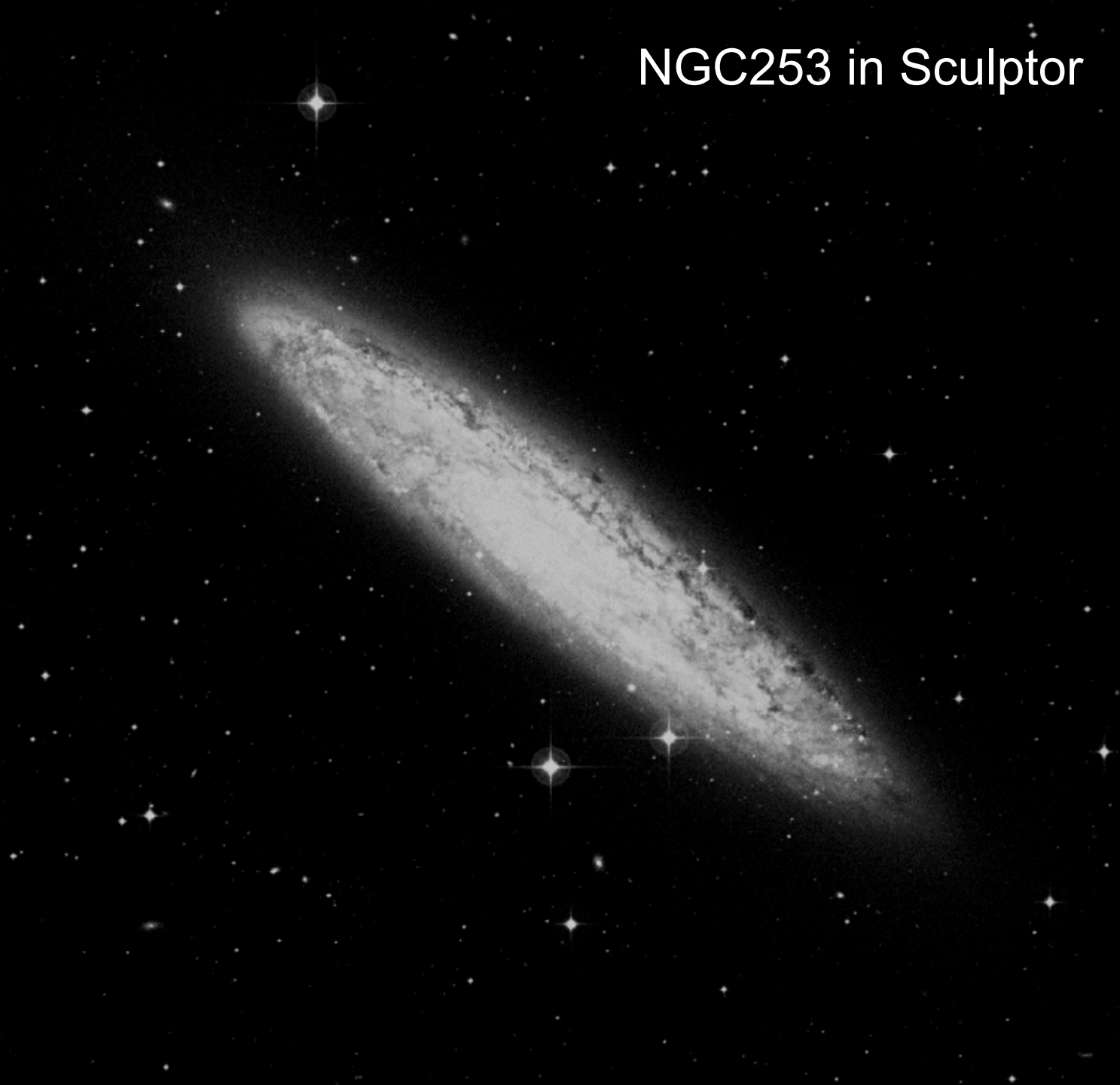
The visible universe

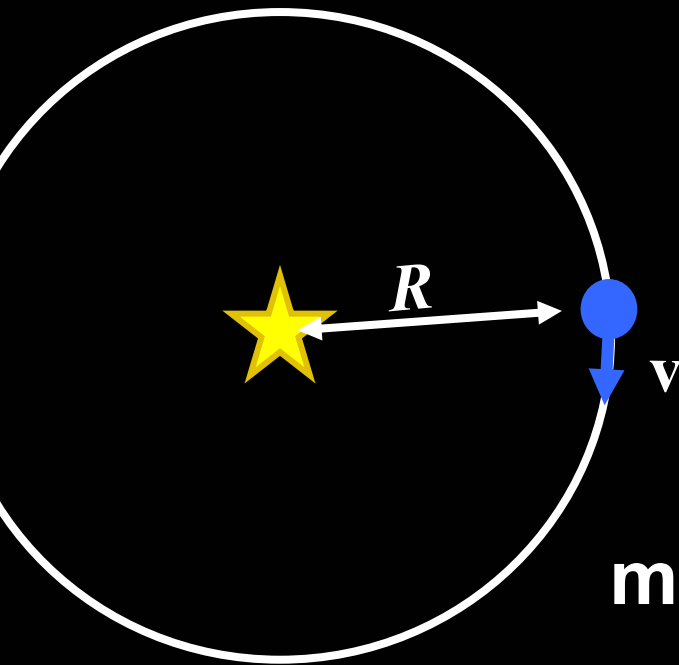


M63

Galaxies

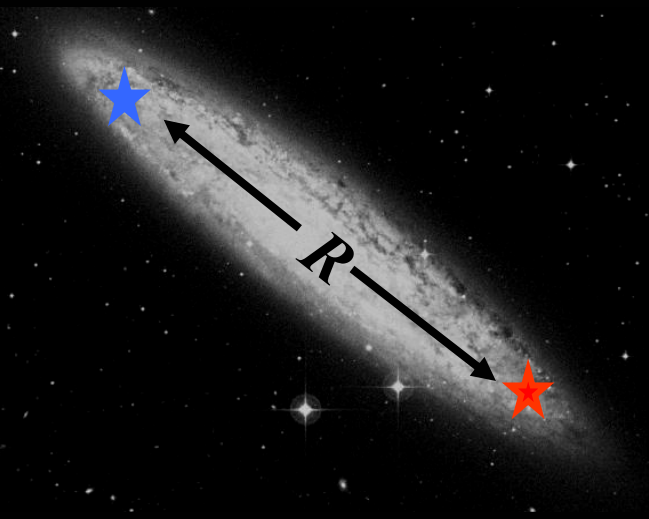
NGC253 in Sculptor





$$\frac{v^2}{R} = \frac{GM_{SUN}}{R^2}$$

measure v & R $\Rightarrow M_{SUN}$



$$\frac{v^2}{R} = \frac{GM_{GALAXY}}{R^2}$$

measure v & R $\Rightarrow M_{GALAXY}$

M33 rotation curve

v (km/s)

100

50

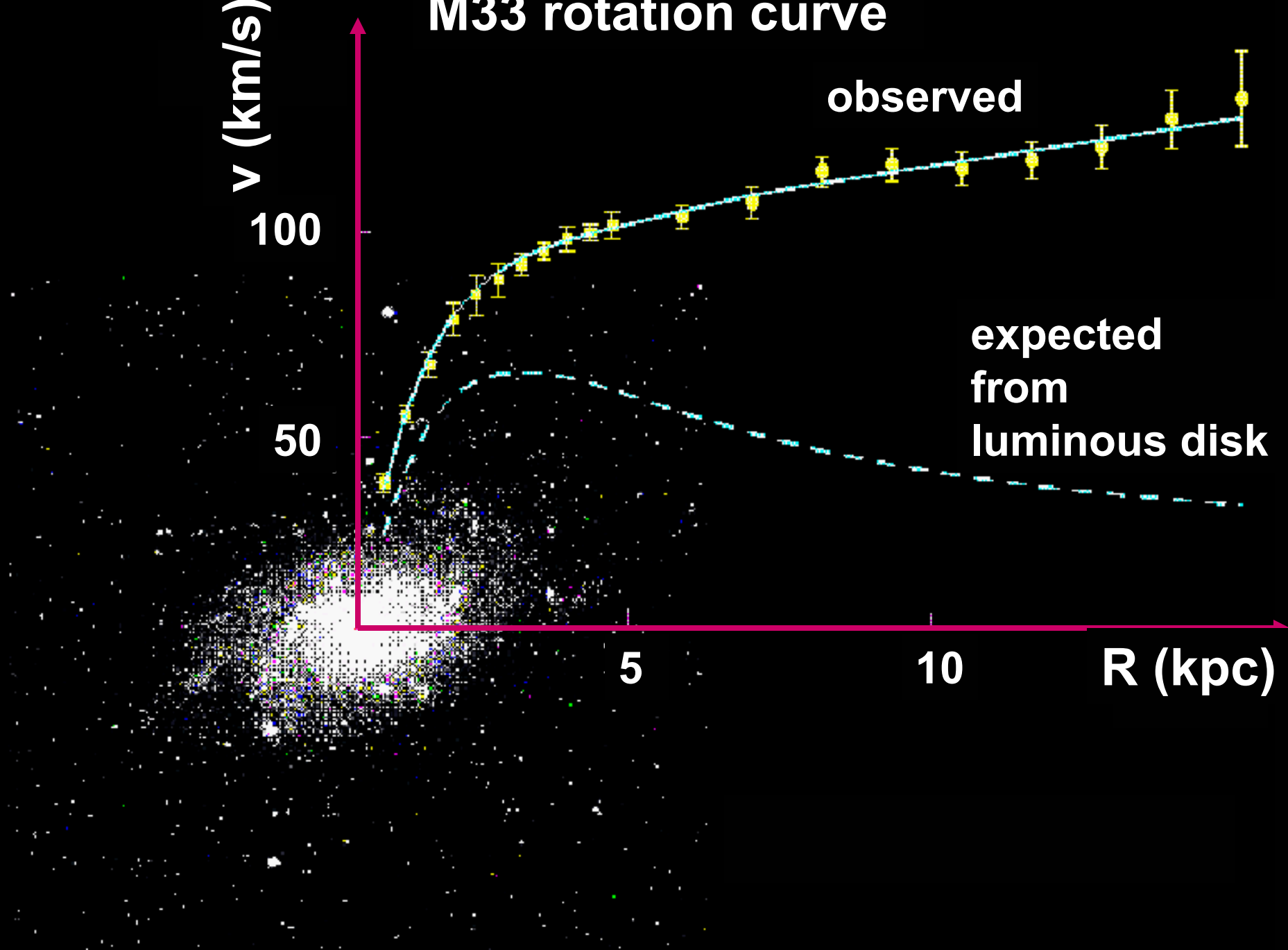
observed

expected
from
luminous disk

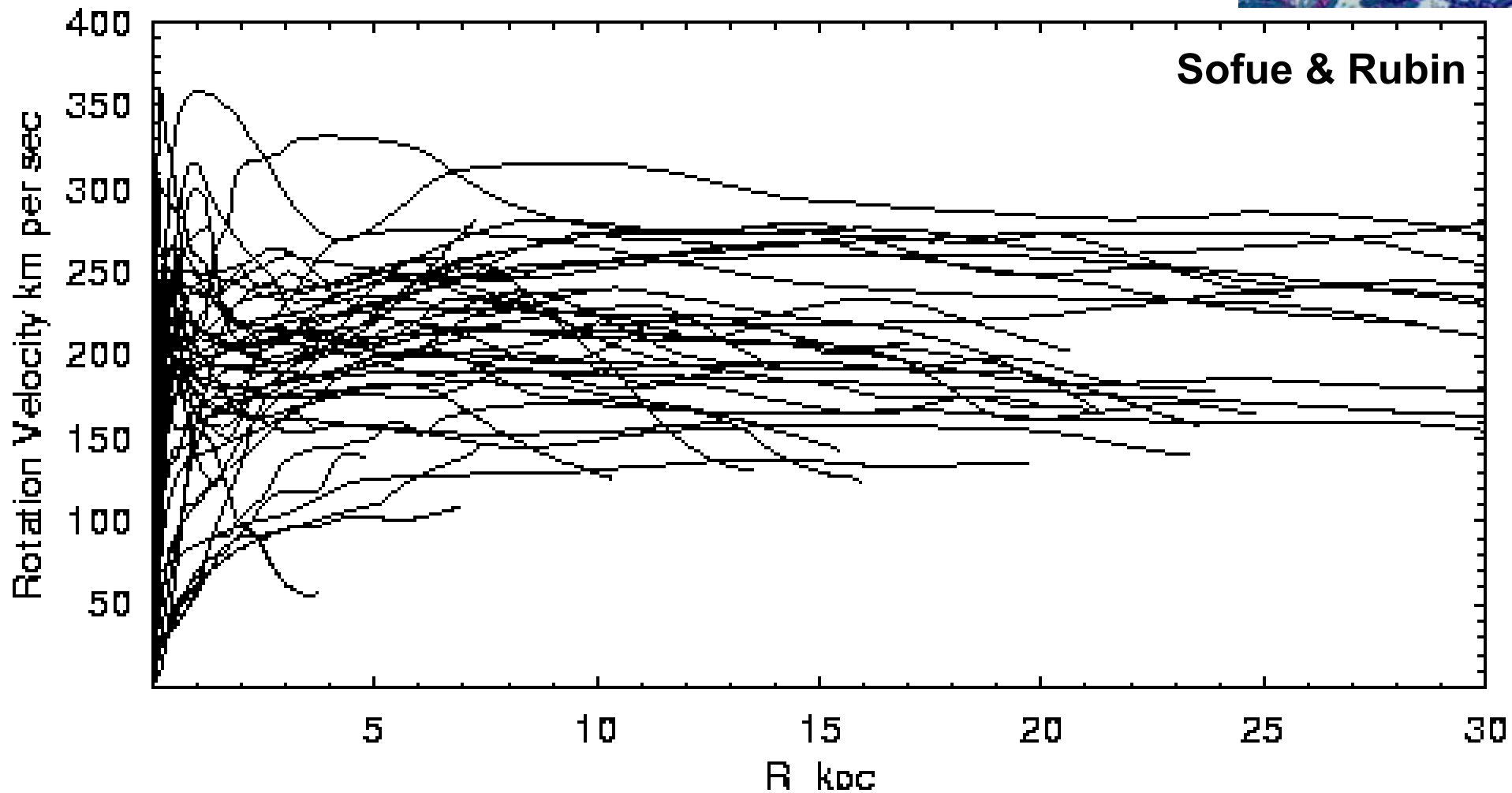
5

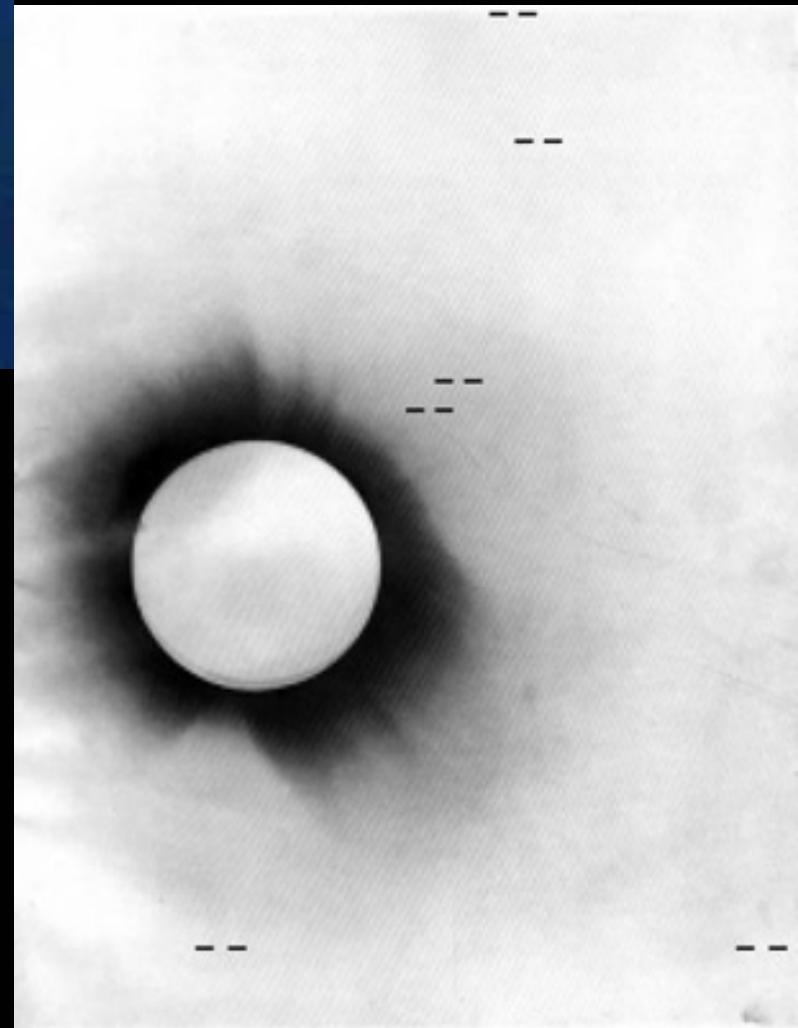
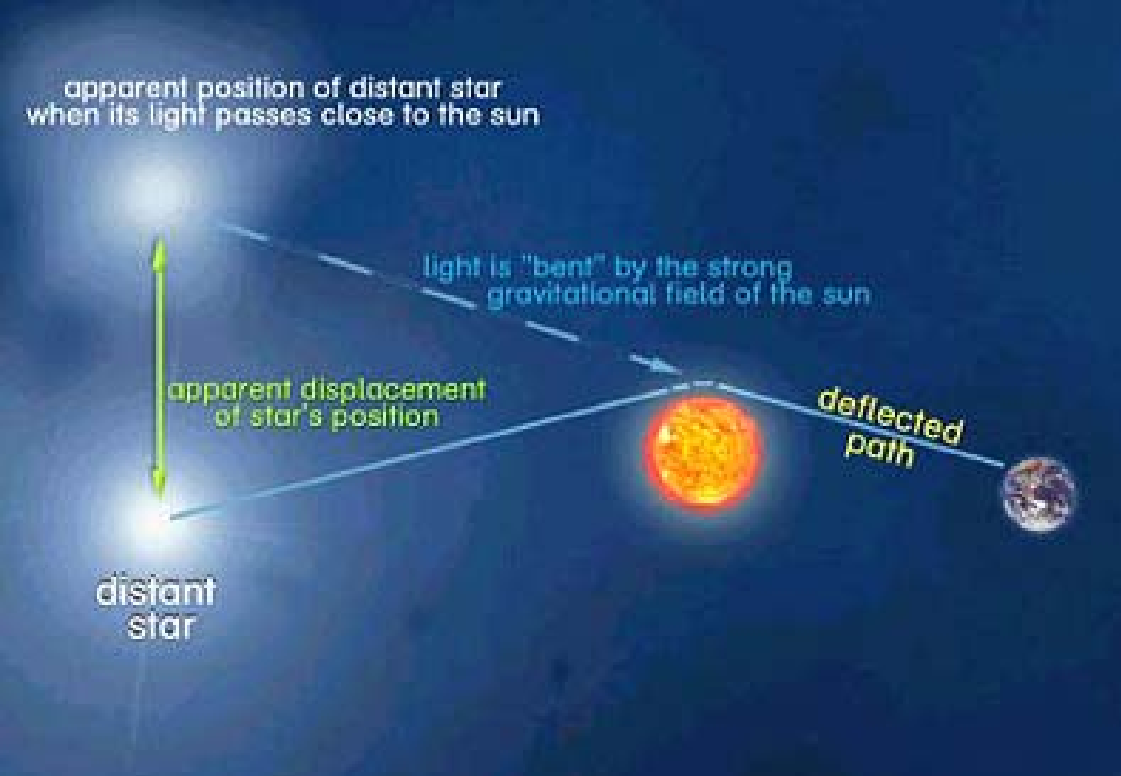
10

R (kpc)

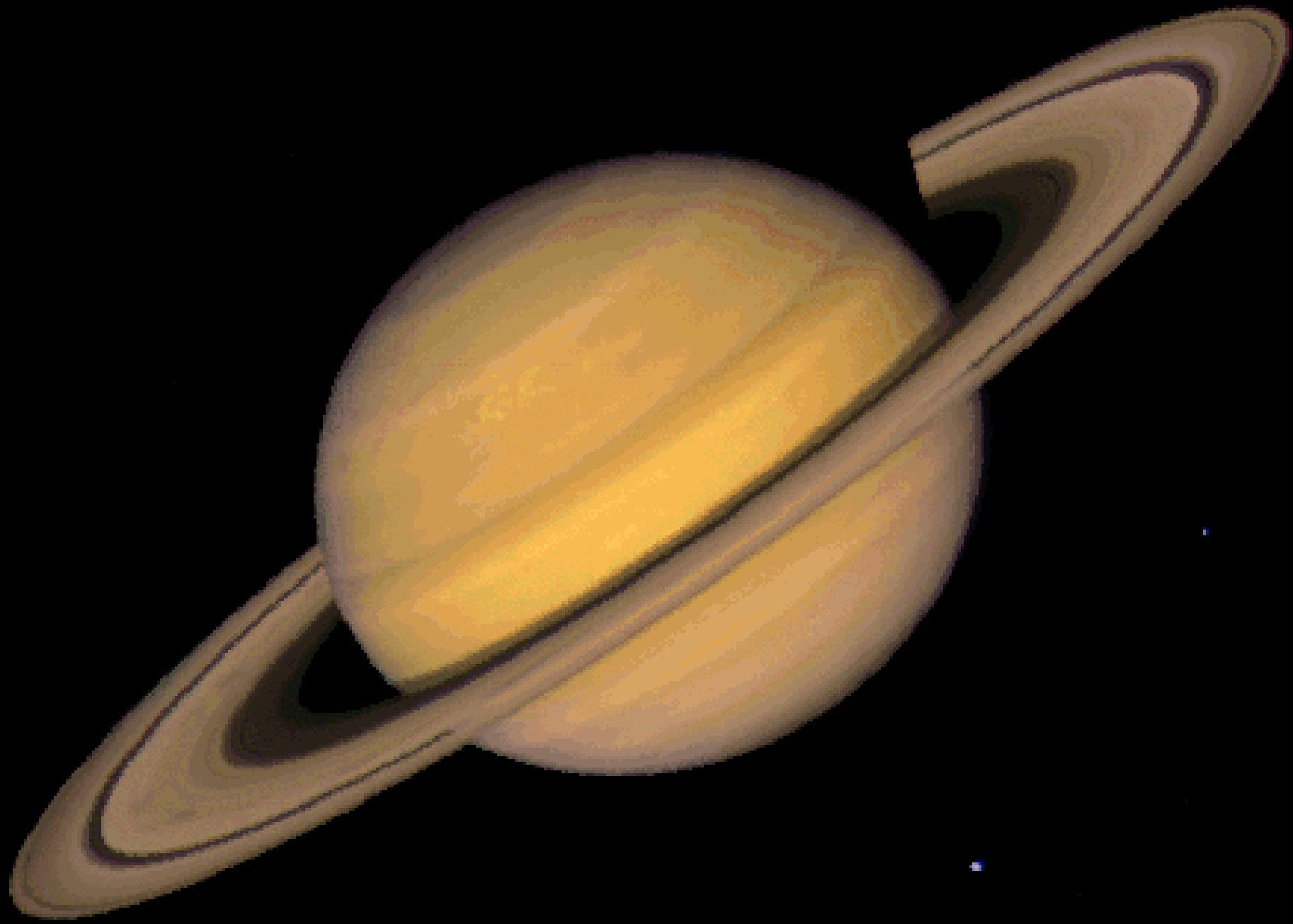


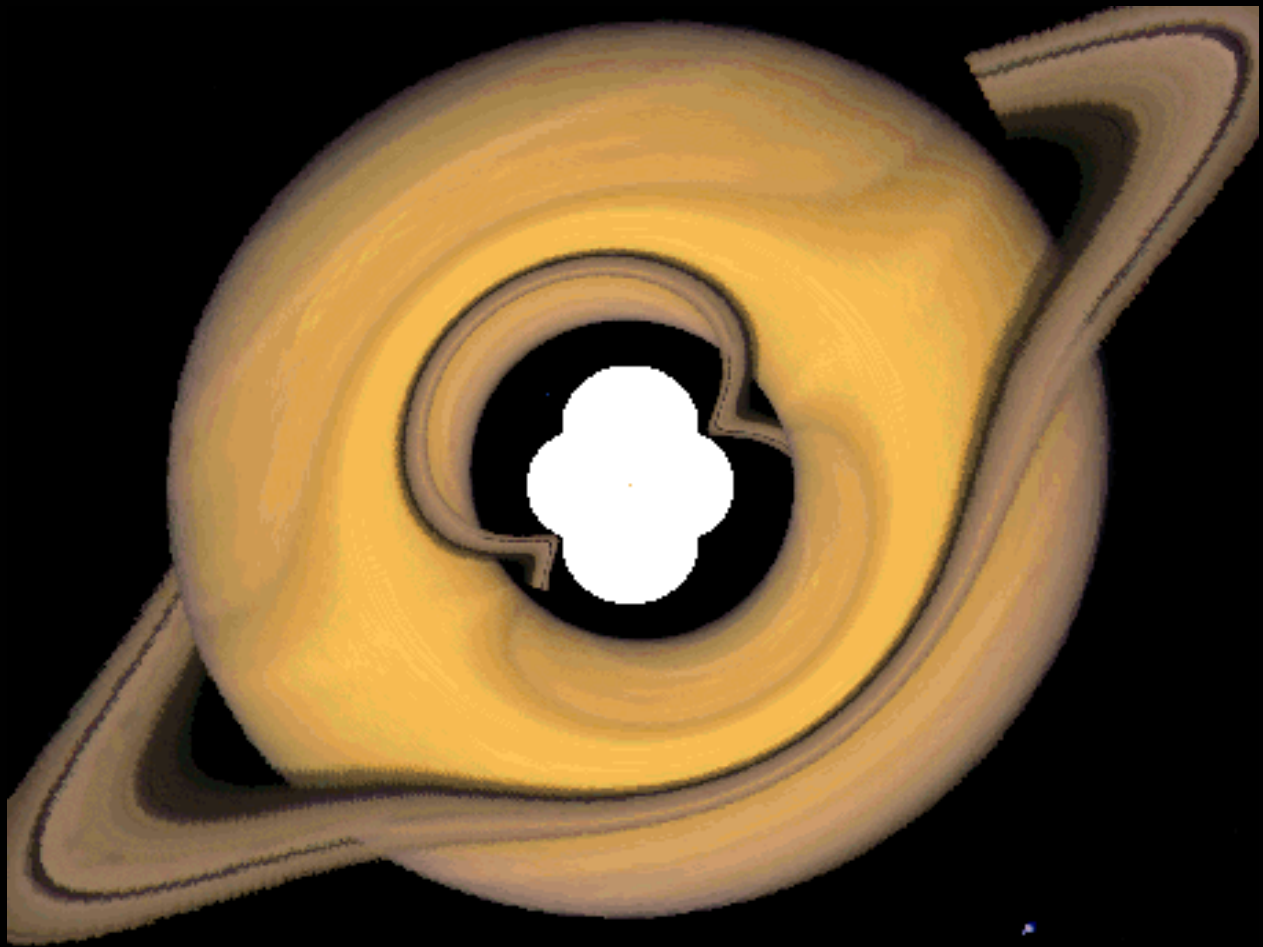
Rotation curves





1919 Eclipse Expedition





Gravitational Lensing





Gravitational Lens in Abell 2218

HST • WFPC2

PF95-14 • ST ScI OPO • April 5, 1995 • W. Couch (UNSW), NASA